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# Association between physical activity, trouble sleeping, and obesity among older Americans: a cross-sectional study based on NHANES data from 2007 to 2018

Xiao Hou[1,2†], Huihui Wang[1,2†], Zhengxing Yang[3], Yuanyuan Jia[1,2], Yifan Lv[4] and Xiaosheng Dong[5,6,7,8*]

## Abstract

**Background** As the global population ages, obesity among older adults has become an increasing public health concern. Lifestyle factors, including physical activity (PA) and sleep, play a critical role in obesity prevention. These behaviors occur within a 24-hour cycle, yet research on the impact of different PA patterns, trouble sleeping, and their combination on obesity in older adults remains limited. This study aimed to explore: (1) the relationship between PA patterns, trouble sleeping, and obesity among older Americans; and (2) the combined effect of PA patterns and trouble sleeping on obesity in this population.

**Methods** A total of 10,891 participants aged 60 and older (55.0% female) from the National Health and Nutrition Examination Survey 2007–2018 were included. Trouble sleeping was assessed using the Sleep Disorder Questionnaire, and PA was measured using the Global Physical Activity Questionnaire. Body mass index (BMI) was calculated from objectively measured weight and height. Multivariate linear regression models were used to estimate the association between PA patterns, trouble sleeping, and BMI.

**Results** Compared to the inactive group, participants in the insufficiently active group ($\beta$ = -0.75; 95% CI = -1.27 to -0.23; $P$ = 0.005), weekend warrior group ($\beta$ = -1.08; 95% CI = -1.88 to -0.28; $P$ = 0.009), and regularly active group ($\beta$ = -1.58; 95% CI = -2.02 to -1.14; $P$ < 0.001) had a significant negative association with BMI. Participants with trouble sleeping exhibited a positive association with BMI compared to those without trouble sleeping ($\beta$ = 0.39; 95% CI = 0.02 to 0.75; $P$ = 0.040). Conversely, among participants with trouble sleeping, those who were regularly active exhibited a negative association with BMI ($\beta$ = -0.56; 95% CI = -1.05 to -0.07; $P$ = 0.027). Additionally, compared to sufficiently active group, both the inactive and insufficiently active groups exhibited a positive association with BMI, regardless of the presence of trouble sleeping.

†Xiao Hou and Huihui Wang have contributed equally to this work and share the first authorship

*Correspondence:
Xiaosheng Dong
dxiaosheng@hotmail.com

Full list of author information is available at the end of the article

**Conclusion** Insufficient PA and trouble sleeping in older adults are positively associated with obesity. Engaging in either a weekend warrior or regular PA lifestyle is negatively associated with obesity. Furthermore, adopting a regularly active lifestyle may mitigate the negative impact of trouble sleeping on obesity. However, regardless of the presence of trouble sleeping, insufficient PA remains positively associated with obesity in older adults.

**Keywords** NHANES, Physical activity, Weekend warrior, Trouble sleeping, Obesity, Cross-sectional study

## Introduction

As the global population ages, there is a corresponding increase in the prevalence of obesity among older adults [1, 2], thereby presenting a serious global epidemic and public health concern [3]. In the United States, 41.0% of adults aged 60 and older are affected by obesity [4]. Obesity not only increases the risk of chronic conditions such as diabetes and hyperlipidemia [5], but also contributes to declines in physical function and quality of life [6]. Moreover, obesity in older adults imposes a substantial economic burden [7], with healthcare costs for individuals with obesity estimated to be 30% higher than those for individuals with normal weight, accounting for 0.7–2.8% of a country's total healthcare expenditure [8]. It is projected that healthcare costs related to obesity and overweight will constitute 16–18% of the total healthcare expenditure in the United States by 2030 [9]. Therefore, addressing obesity in older adults is imperative for both societal and economic development.

Lifestyle factors play a crucial role in obesity prevention among older adults [10, 11]. Global obesity prevention and management strategies emphasize lifestyle modifications, particularly increasing physical activity (PA) and maintaining healthy sleep habits [12, 13]. Sufficient PA promotes fat oxidation, while sound sleep states help maintain normal levels of leptin and ghrelin, thereby effectively preventing obesity [14, 15]. The World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) recommend that older adults engage in at least 150 min of moderate-intensity physical activity (MPA), 75 min of vigorous-intensity physical activity (VPA), or an equivalent combination per week [16–18]. As societal pace quickens, the weekend warrior pattern (meeting the WHO and CDC recommended PA levels and engaging in PA only 1–2 times per week) has gained popularity. This pattern has demonstrated effectiveness in reducing the risk of cardiovascular diseases, metabolic syndrome, and obesity [19–23]. However, PA is a multidimensional behavior that encompasses frequency, duration, and intensity. It remains unclear whether weekend warrior and other PA patterns offer different benefits for obesity prevention among older adults due to variations in these parameters [24]. Additionally, sleep health is an essential factor in obesity prevention. However, epidemiological studies indicate that 36–50% of community-dwelling older adults experience trouble sleeping [25, 26], which may contribute to obesity by affecting carbohydrate metabolism and endocrine function [3, 27]. Despite growing recognition of sleep's role in obesity, high-quality empirical studies examining the association between trouble sleeping and obesity in older adults remain limited.

PA and sleep, both regulated within the 24-hour circadian cycle, may interact to influence obesity risk through biological and behavioral pathways [13]. Engaging in sufficient PA may alleviate the adverse effects of trouble sleeping and their subsequent impact on obesity by promoting a stable circadian rhythm and healthy sleep patterns [28–30]. Conversely, fragmented sleep may lead to endocrine dysregulation, impaired mental health, and reduced PA levels, further increasing obesity risk [31]. Given these interconnections, increasing PA among individuals with trouble sleeping may help mitigate the relationship between sleep disturbances and weight gain [31, 32]. While previous studies suggest that exercise improves sleep quality and reduces obesity risk among adolescents [33–35] and adults [31, 36], its impact on older adults remains unclear. Furthermore, specific PA recommendations for obesity prevention in older adults with trouble sleeping have yet to be established. It is also uncertain whether different sleep profiles influence obesity risk differently among inadequately active older adults. Therefore, high-quality studies are needed to elucidate the combined impact of PA patterns and trouble sleeping on obesity in older adults.

Therefore, this study aims to use data from the National Health and Nutrition Examination Survey (NHANES) to explore: (1) the relationship between PA patterns, trouble sleeping, and obesity among older Americans; and (2) the combined effect of PA patterns and trouble sleeping on obesity in this population.

## Methods

### Study design and participants

This study employed a cross-sectional design using data from the NHANES. The survey was conducted by the CDC and was updated biennially [37]. NHANES is an ongoing national survey designed to assess the health and nutritional status of the U.S. population, with a focus on disease prevalence and associated risk factors. Data were collected through questionnaires and physical examinations, encompassing socio-demographic, dietary, and medical information. Ethical approval for NHANES was granted by the National Center for Health Statistics. All participants provided written consent to participate in NHANES.

A total of 11,910 participants aged 60 years and older were included from the 2007–2018 NHANES cycles. After excluding 1,019 participants with missing data on physical activity ($n = 56$), trouble sleeping ($n = 5$), body mass index (BMI) ($n = 830$), education attainment ($n = 27$), currently married/partnered ($n = 7$), smoking history ($n = 9$), hypertension ($n = 19$), diabetes ($n = 7$), cancer ($n = 10$), stroke ($n = 28$), and heart disease ($n = 21$), the final analytical sample comprised 10,891 participants. Figure 1 shows the flowchart of this study.

## Data collection

### *Trouble sleeping*

Based on previous studies [38–40], trouble sleeping was assessed using the Sleep Disorder Questionnaire, and participants were asked, "Have you ever told a doctor or other health professional that you have trouble sleeping". Response options included "Yes", "No", "Refused", and "Do not know". Those who answered "yes/no" were classified as individuals with/without trouble sleeping for subsequent analysis, while those who responded "Refused" or "Do not know" were considered as missing data.

### *Physical activity*

PA was self-reported using the Global Physical Activity Questionnaire (GPAQ), developed by the WHO [41]. This questionnaire assesses the frequency, intensity, and duration of PA in various domains, including occupation, transportation, and leisure time [42].The GPAQ had previously shown moderate reliability ($\kappa$ 0.67–0.73) and correlation with the International Physical Activity Questionnaire ($\kappa$ 0.45–0.65) [43]. Metabolic equivalent task (MET) values were employed to quantify the intensity of different types of PA, such as VPA (MET = 8), MPA (MET = 4), and walking or bicycling for transportation PA (MET = 4) [44]. Total weekly energy expenditure was calculated by multiplying the MET value by the number of PA minutes per week (MET-minutes/week) [45]. For instance, 150 min of MPA per week equates to 600 MET-min/week (4 MET*150 minutes) and 75 min of VPA per week would equate to 600 MET-min/week (8 MET*75 minutes).

PA patterns were categorized into four groups based on the frequency of moderate-to-vigorous intensity physical activity (MVPA) per week and total energy expenditure: (1) inactive group (the total energy expenditure of MVPA = 0 MET-min/week); (2) insufficiently active group (the total energy expenditure of MVPA < 600 MET-min/week); (3) weekend warrior group (the total energy expenditure of MVPA ≥ 600 MET-min/week, the frequency of MVPA ≤ 2 sessions per week); (4) regularly active group (the total energy expenditure of MVPA ≥ 600 MET-min/week, the frequency of MVPA ≥ 3 sessions per week) [16–18, 46]. Under the classification of PA patterns, further categorization was performed based on the total energy expenditure, frequency, and intensity [47]. For the total energy expenditure, the insufficiently active group was divided into four subgroups, including 1 to 149

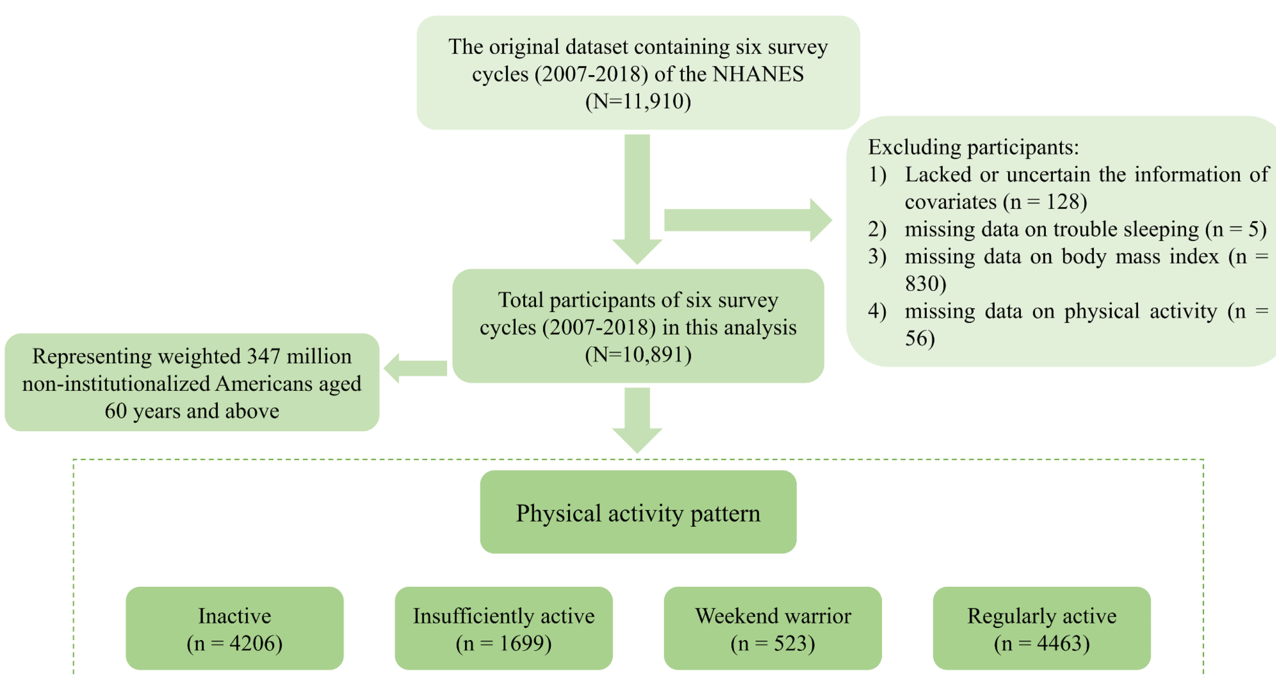



**Fig. 1** The flowchart of study design

MET-min/week, 150 to 299 MET-min/week, 300 to 449 MET-min/week, and 450 to 599 MET-min/week. And the weekend warrior group and regularly active group was divided into four subgroups, including 600 to 1199 MET-min/week, 1200 to 1799 MET-min/week, 1800 to 2399 MET-min/week, and ≥ 2400 MET-min/week. For the frequency, the weekend warrior group was divided into two subgroups, including 1 session/week and 2 session/week. And the regularly active group was divided into four subgroups, including 3 session/week, 4 session/week, 5 session/week, and ≥ 6 session/week. The intensity was calculated by the proportion of the energy expenditure of VPA to the energy expenditure of total MVPA and categorized into 4 groups, including ≤ 25%, 25.01 to 50%, 50.01 to 75%, and ≥ 75.01%.

#### *BMI*

BMI was calculated as weight (kg) divided by height squared ($m^2$). Both height and weight were measured during physical examinations by medical professionals. Height was measured using a stadiometer, with an accuracy of 0.1 centimeters, and weight was measured using an electronic scale in accordance with the standard procedures at the Mobile Examination Center (MEC) (accurate to 0.1 kg) [48, 49].

#### *Covariates*

Covariates were selected based on prior research [44, 50–52], and included sociodemographic characteristics, lifestyle behaviors, and clinical conditions. More specifically, sociodemographic characteristics included age (60–69, 70–80), sex (male, female), currently married/partnered (no, yes), education attainment (less than 9th grade, 9-11th grade, high school graduate or equivalent, college or associates degree, or college graduate or above), and race/ethnicity (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, or other race). Lifestyle behaviors were assessed based on smoking history, wherein participants were categorized as having a smoking history if they had smoked a minimum of 100 cigarettes throughout their lives. Clinical characteristics included hypertension, diabetes, cancer, stroke, and heart disease. Hypertension was defined as having at least one of the following criteria: (1) systolic blood pressure ≥ 140 mmHg, (2) diastolic blood pressure ≥ 90 mmHg, and (3) having been diagnosed by a doctor or other health professional. Diabetes, cancer, stroke, and heart disease were determined based on a doctor's or other health professional's declaration of the respective diseases.

### Statistical analysis

This study utilized publicly available data from six NHANES cycles (2007–2008, 2009–2010, 2011–2012, 2013–2014, 2015–2016, and 2017–2018). Sample weights were adjusted by dividing the 2-year survey weights (WTMEC2YR) by the number of cycles (six). NHANES incorporates a complex survey design with clustering (SDMVPSU) and stratification (SDMVSTRA). Accordingly, all descriptive and correlational analyses accounted for sample weights, clustering, and stratification to meet the analytical requirements of the NHANES data, resulting in nationally representative sample statistics [53].

Descriptive statistics were calculated for the distribution of participant characteristics and the weighted representation of the U.S. population. Continuous variables presented as mean values (standard deviations, SD), and categorical variables as counts and percentages. Univariate and multivariate linear regression analyses were conducted to investigate the associations between PA patterns, trouble sleeping, and the combinations of these two factors in relation to BMI.

To investigate the relationship between PA patterns and BMI, different PA patterns were compared using both inactive and regularly active groups as reference groups. Subsequently, using the inactive group as the reference, participants in different PA patterns were further categorized based on total energy expenditure, frequency, and the proportion of VPA to MVPA.

To explore the combined effect of PA patterns and trouble sleeping, participants without trouble sleeping were used as the reference group, and those with trouble sleeping were categorized by PA pattern. Additionally, using the group meeting PA guidelines as the reference, the inactive and insufficiently active groups were further categorized based on trouble sleeping status to investigate the relationship with BMI.

Results were presented as beta coefficients ($\beta$) with 95% confidence intervals (CIs). The unadjusted model included no covariates, Model 1 adjusted for sex, age, education attainment, currently married/partnered, and race/ethnicity. Model 2 further adjusted for smoking history, hypertension, diabetes, stroke, heart disease, and cancer. All statistical tests were conducted on a two-sided basis, with $P$-values < 0.05 being deemed statistically significant. All statistical analyses were performed using R statistical software (version 4.2.2) with the "survey" package.

## Results

### Participant characteristics

The general characteristics of the study participants are summarized in Table 1. A weighted sample of 10,891 participants represented 347 million community-dwelling older adults in the United States, with 45.0% ($n$ = 5346) being male. All participants were aged 60 years and older, 53.1% ($n$ = 5,501) were aged 60–69, and 46.9% ($n$ = 5,390) were aged 70–80. The majority were non-Hispanic White ($n$ = 5139, 77.0%). The mean BMI was 29.2 (± 6.3) kg/$m^2$,

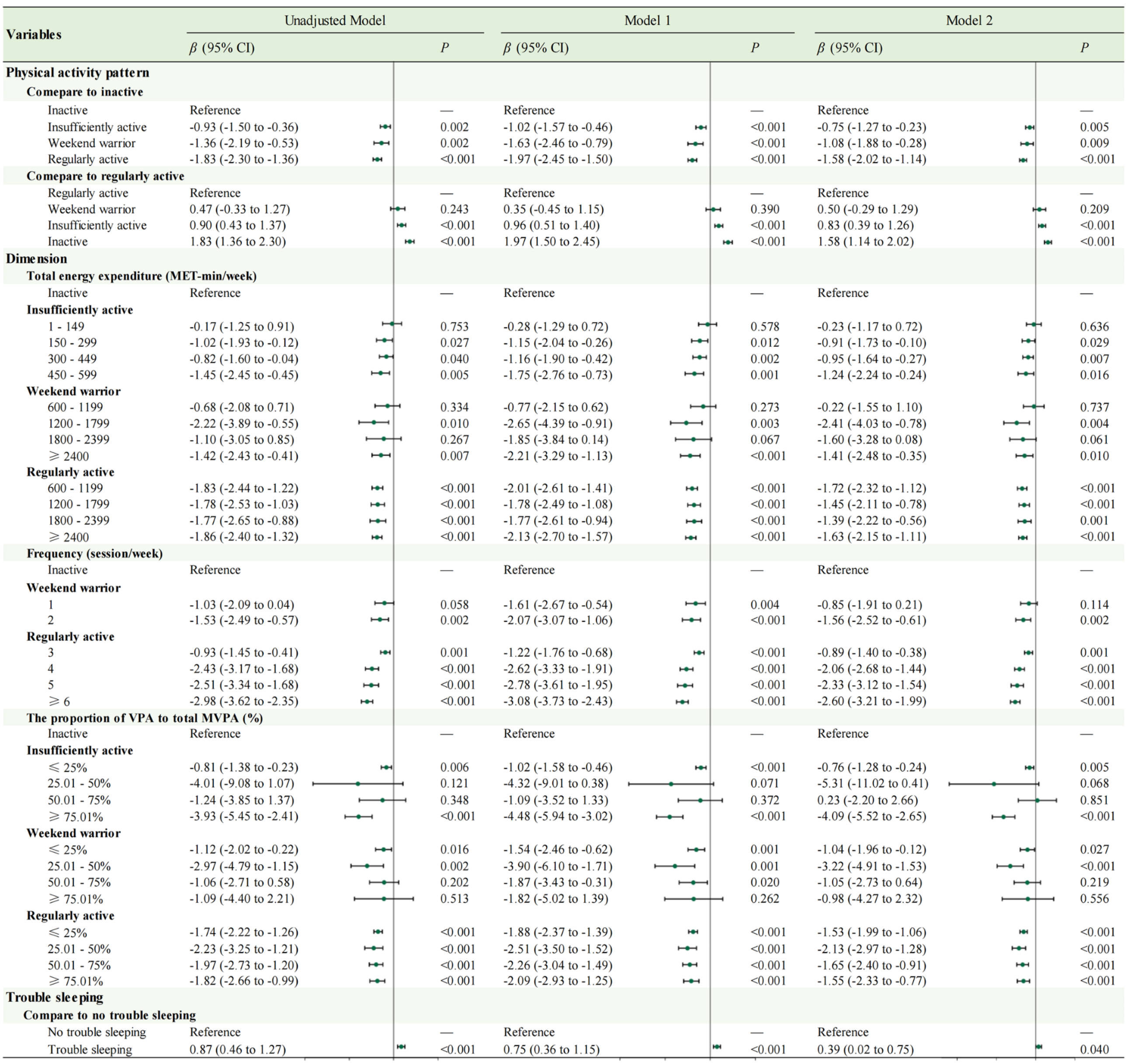
**Table 1** Survey-weighted detailed demographic characteristics of the older Americans

| Characteristics | Estimate U.S population (*n*) | Overall |
|---|---|---|
| **Sample**, *n* **(%)** | 347,273,353 | 10,891 (100.0) |
| **Age**, **years**, *n* **(%)** | | |
| 60–69 | 184,414,780 | 5501 (53.1) |
| 70–80 | 162,858,573 | 5390 (46.9) |
| **Sex**, *n* **(%)** | | |
| Female | 191,122,578 | 5545 (55.0) |
| Male | 156,150,775 | 5346 (45.0) |
| **Race/ethnicity**, *n* **(%)** | | |
| Mexican American | 14,613,092 | 1321 (4.2) |
| Other Hispanic | 12,762,960 | 1119 (3.7) |
| Non-Hispanic White | 267,365,412 | 5139 (77.0) |
| Non-Hispanic Black | 30,998,141 | 2341 (8.9) |
| Other race | 21,533,748 | 971 (6.2) |
| **Education attainment**, *n* **(%)** | | |
| Less than 9th grade | 27,889,489 | 1759 (8.1) |
| 9-11th grade | 36,607,241 | 1563 (10.5) |
| High school graduate or equivalent | 85,594,361 | 2537 (24.6) |
| College or associates degree | 99,284,166 | 2814 (28.6) |
| College graduate or above | 97,898,096 | 2218 (28.2) |
| **Currently married/partnered**, *n* **(%)** | | |
| No | 126,615,783 | 4620 (36.5) |
| Yes | 220,657,570 | 6271 (63.5) |
| **BMI**, **kg/m$^2$**, **M (SD)** | — | 29.2 (6.3) |
| **Smoking history**, *n* **(%)** | | |
| No | 173,730,619 | 5414 (50.0) |
| Yes | 173,542,734 | 5477 (50.0) |
| **Hypertension**, *n* **(%)** | | |
| No | 144,082,745 | 4188 (41.5) |
| Yes | 203,190,608 | 6703 (58.5) |
| **Diabetes**, *n* **(%)** | | |
| No | 276,084,949 | 8194 (79.5) |
| Yes | 71,188,404 | 2697 (20.5) |
| **Cancer**, *n* **(%)** | | |
| No | 260,527,413 | 8644 (75.0) |
| Yes | 86,745,940 | 2247 (25.0) |
| **Stroke**, *n* **(%)** | | |
| No | 322,247,976 | 10,005 (92.8) |
| Yes | 25,025,377 | 886 (7.2) |
| **Heart disease**, *n* **(%)** | | |
| No | 317,065,262 | 9869 (91.3) |
| Yes | 30,208,091 | 1022 (8.7) |
| **Trouble sleeping**, *n* **(%)** | | |
| No | 234,462,603 | 7674 (67.5) |
| Yes | 112,810,750 | 3217 (32.5) |
| **Physical activity pattern**, *n* **(%)** | | |
| Inactive | 117,515,000 | 4206 (33.8) |
| Insufficiently active | 54,403,915 | 1699 (15.7) |
| Weekend warrior | 20,484,178 | 523 (5.9) |
| Regularly active | 154,870,260 | 4463 (44.6) |

Percentages represent the proportion of the weighted sample in the United States population and 32.5% ($n = 3217$) reported trouble sleeping. Regarding PA, 33.8% ($n = 4206$) of participants did not engage in MVPA, 15.7% ($n = 1699$) were insufficiently active, 5.9% ($n = 523$) were weekend warriors, and 44.6% ($n = 4463$) were regularly active.

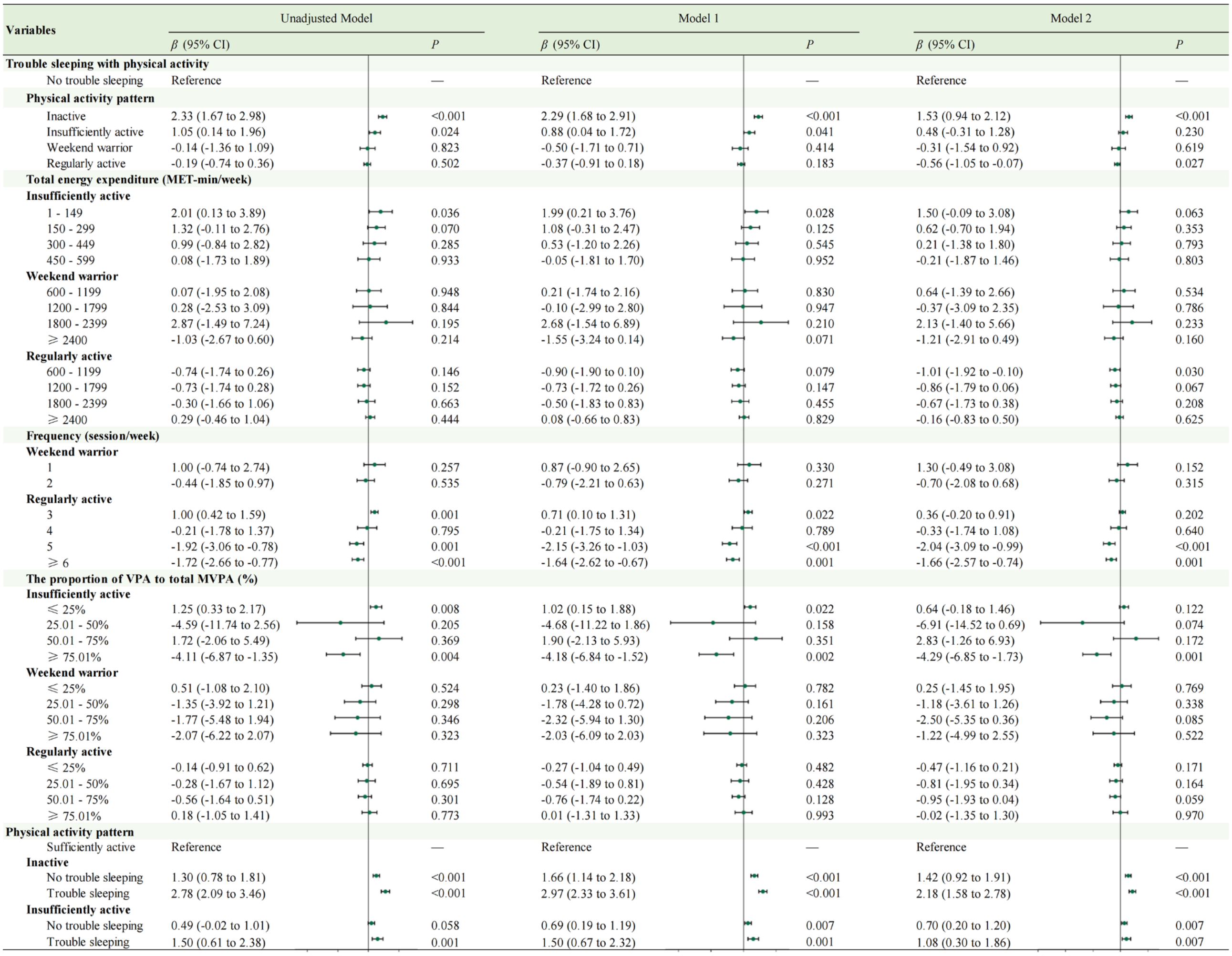
## Relationship between PA patterns, trouble sleeping, and BMI

Figure 2 illustrates the relationship between PA patterns, trouble sleeping, and BMI. After adjusting for all covariates, compared to the inactive group, the insufficiently active group ($\beta$ = -0.75; 95% CI = -1.27 to -0.23; $P = 0.005$), weekend warrior group ($\beta$ = -1.08; 95% CI = -1.88 to -0.28; $P = 0.009$), and regularly active group ($\beta$ = -1.58; 95% CI = -2.02 to -1.14; $P < 0.001$) were all negatively associated with BMI. When the regularly active group was used as the reference, no significant association was observed between the weekend warrior group and BMI, while the insufficiently active group ($\beta = 0.83$; 95% CI = 0.39 to 1.26; $P < 0.001$) and inactive group ($\beta = 1.58$; 95% CI = 1.14 to 2.02; $P < 0.001$) showed a significant positive association with BMI. In terms of total



| Variables | Unadjusted Model β (95% CI) | P | Model 1 β (95% CI) | P | Model 2 β (95% CI) | P |
|---|---|---|---|---|---|---|
| **Physical activity pattern** | | | | | | |
| **Comepare to inactive** | | | | | | |
| Inactive | Reference | — | Reference | — | Reference | — |
| Insufficiently active | -0.93 (-1.50 to -0.36) | 0.002 | -1.02 (-1.57 to -0.46) | <0.001 | -0.75 (-1.27 to -0.23) | 0.005 |
| Weekend warrior | -1.36 (-2.19 to -0.53) | 0.002 | -1.63 (-2.46 to -0.79) | <0.001 | -1.08 (-1.88 to -0.28) | 0.009 |
| Regularly active | -1.83 (-2.30 to -1.36) | <0.001 | -1.97 (-2.45 to -1.50) | <0.001 | -1.58 (-2.02 to -1.14) | <0.001 |
| **Comepare to regularly active** | | | | | | |
| Regularly active | Reference | — | Reference | — | Reference | — |
| Weekend warrior | 0.47 (-0.33 to 1.27) | 0.243 | 0.35 (-0.45 to 1.15) | 0.390 | 0.50 (-0.29 to 1.29) | 0.209 |
| Insufficiently active | 0.90 (0.43 to 1.37) | <0.001 | 0.96 (0.51 to 1.40) | <0.001 | 0.83 (0.39 to 1.26) | <0.001 |
| Inactive | 1.83 (1.36 to 2.30) | <0.001 | 1.97 (1.50 to 2.45) | <0.001 | 1.58 (1.14 to 2.02) | <0.001 |
| **Dimension** | | | | | | |
| **Total energy expenditure (MET-min/week)** | | | | | | |
| Inactive | Reference | — | Reference | — | Reference | — |
| **Insufficiently active** | | | | | | |
| 1 - 149 | -0.17 (-1.25 to 0.91) | 0.753 | -0.28 (-1.29 to 0.72) | 0.578 | -0.23 (-1.17 to 0.72) | 0.636 |
| 150 - 299 | -1.02 (-1.93 to -0.12) | 0.027 | -1.15 (-2.04 to -0.26) | 0.012 | -0.91 (-1.73 to -0.10) | 0.029 |
| 300 - 449 | -0.82 (-1.60 to -0.04) | 0.040 | -1.16 (-1.90 to -0.42) | 0.002 | -0.95 (-1.64 to -0.27) | 0.007 |
| 450 - 599 | -1.45 (-2.45 to -0.45) | 0.005 | -1.75 (-2.76 to -0.73) | 0.001 | -1.24 (-2.24 to -0.24) | 0.016 |
| **Weekend warrior** | | | | | | |
| 600 - 1199 | -0.68 (-2.08 to 0.71) | 0.334 | -0.77 (-2.15 to 0.62) | 0.273 | -0.22 (-1.55 to 1.10) | 0.737 |
| 1200 - 1799 | -2.22 (-3.89 to -0.55) | 0.010 | -2.65 (-4.39 to -0.91) | 0.003 | -2.41 (-4.03 to -0.78) | 0.004 |
| 1800 - 2399 | -1.10 (-3.05 to 0.85) | 0.267 | -1.85 (-3.84 to 0.14) | 0.067 | -1.60 (-3.28 to 0.08) | 0.061 |
| ≥ 2400 | -1.42 (-2.43 to -0.41) | 0.007 | -2.21 (-3.29 to -1.13) | <0.001 | -1.41 (-2.48 to -0.35) | 0.010 |
| **Regularly active** | | | | | | |
| 600 - 1199 | -1.83 (-2.44 to -1.22) | <0.001 | -2.01 (-2.61 to -1.41) | <0.001 | -1.72 (-2.32 to -1.12) | <0.001 |
| 1200 - 1799 | -1.78 (-2.53 to -1.03) | <0.001 | -1.78 (-2.49 to -1.08) | <0.001 | -1.45 (-2.11 to -0.78) | <0.001 |
| 1800 - 2399 | -1.77 (-2.65 to -0.88) | <0.001 | -1.77 (-2.61 to -0.94) | <0.001 | -1.39 (-2.22 to -0.56) | 0.001 |
| ≥ 2400 | -1.86 (-2.40 to -1.32) | <0.001 | -2.13 (-2.70 to -1.57) | <0.001 | -1.63 (-2.15 to -1.11) | <0.001 |
| **Frequency (session/week)** | | | | | | |
| Inactive | Reference | — | Reference | — | Reference | — |
| **Weekend warrior** | | | | | | |
| 1 | -1.03 (-2.09 to 0.04) | 0.058 | -1.61 (-2.67 to -0.54) | 0.004 | -0.85 (-1.91 to 0.21) | 0.114 |
| 2 | -1.53 (-2.49 to -0.57) | 0.002 | -2.07 (-3.07 to -1.06) | <0.001 | -1.56 (-2.52 to -0.61) | 0.002 |
| **Regularly active** | | | | | | |
| 3 | -0.93 (-1.45 to -0.41) | 0.001 | -1.22 (-1.76 to -0.68) | <0.001 | -0.89 (-1.40 to -0.38) | 0.001 |
| 4 | -2.43 (-3.17 to -1.68) | <0.001 | -2.62 (-3.33 to -1.91) | <0.001 | -2.06 (-2.68 to -1.44) | <0.001 |
| 5 | -2.51 (-3.34 to -1.68) | <0.001 | -2.78 (-3.61 to -1.95) | <0.001 | -2.33 (-3.12 to -1.54) | <0.001 |
| ≥ 6 | -2.98 (-3.62 to -2.35) | <0.001 | -3.08 (-3.73 to -2.43) | <0.001 | -2.60 (-3.21 to -1.99) | <0.001 |
| **The proportion of VPA to total MVPA (%)** | | | | | | |
| Inactive | Reference | — | Reference | — | Reference | — |
| **Insufficiently active** | | | | | | |
| ≤ 25% | -0.81 (-1.38 to -0.23) | 0.006 | -1.02 (-1.58 to -0.46) | <0.001 | -0.76 (-1.28 to -0.24) | 0.005 |
| 25.01 - 50% | -4.01 (-9.08 to 1.07) | 0.121 | -4.32 (-9.01 to 0.38) | 0.071 | -5.31 (-11.02 to 0.41) | 0.068 |
| 50.01 - 75% | -1.24 (-3.85 to 1.37) | 0.348 | -1.09 (-3.52 to 1.33) | 0.372 | 0.23 (-2.20 to 2.66) | 0.851 |
| ≥ 75.01% | -3.93 (-5.45 to -2.41) | <0.001 | -4.48 (-5.94 to -3.02) | <0.001 | -4.09 (-5.52 to -2.65) | <0.001 |
| **Weekend warrior** | | | | | | |
| ≤ 25% | -1.12 (-2.02 to -0.22) | 0.016 | -1.54 (-2.46 to -0.62) | 0.001 | -1.04 (-1.96 to -0.12) | 0.027 |
| 25.01 - 50% | -2.97 (-4.79 to -1.15) | 0.002 | -3.90 (-6.10 to -1.71) | 0.001 | -3.22 (-4.91 to -1.53) | <0.001 |
| 50.01 - 75% | -1.06 (-2.71 to 0.58) | 0.202 | -1.87 (-3.43 to -0.31) | 0.020 | -1.05 (-2.73 to 0.64) | 0.219 |
| ≥ 75.01% | -1.09 (-4.40 to 2.21) | 0.513 | -1.82 (-5.02 to 1.39) | 0.262 | -0.98 (-4.27 to 2.32) | 0.556 |
| **Regularly active** | | | | | | |
| ≤ 25% | -1.74 (-2.22 to -1.26) | <0.001 | -1.88 (-2.37 to -1.39) | <0.001 | -1.53 (-1.99 to -1.06) | <0.001 |
| 25.01 - 50% | -2.23 (-3.25 to -1.21) | <0.001 | -2.51 (-3.50 to -1.52) | <0.001 | -2.13 (-2.97 to -1.28) | <0.001 |
| 50.01 - 75% | -1.97 (-2.73 to -1.20) | <0.001 | -2.26 (-3.04 to -1.49) | <0.001 | -1.65 (-2.40 to -0.91) | <0.001 |
| ≥ 75.01% | -1.82 (-2.66 to -0.99) | <0.001 | -2.09 (-2.93 to -1.25) | <0.001 | -1.55 (-2.33 to -0.77) | <0.001 |
| **Trouble sleeping** | | | | | | |
| **Compare to no trouble sleeping** | | | | | | |
| No trouble sleeping | Reference | — | Reference | — | Reference | — |
| Trouble sleeping | 0.87 (0.46 to 1.27) | <0.001 | 0.75 (0.36 to 1.15) | <0.001 | 0.39 (0.02 to 0.75) | 0.040 |

**Fig. 2** The association between PA patterns, trouble sleeping, and BMI in the older Americans. Unadjusted Model: No adjustment for covariates. Model 1: Age, sex, education attainment, currently married/partnered, and race/ethnicity were adjusted. Model 2 for PA patterns: Adjusted for smoking history, trouble sleeping, hypertension, diabetes, stroke, heart disease, and cancer in addition to Model 1. Model 2 for trouble sleeping: Adjusted for smoking history, PA patterns, hypertension, diabetes, stroke, heart disease, and cancer in addition to Model 1



| Variables | Unadjusted Model | | Model 1 | | Model 2 | |
|---|---|---|---|---|---|---|
| | $\beta$ (95% CI) | *P* | $\beta$ (95% CI) | *P* | $\beta$ (95% CI) | *P* |
| **Trouble sleeping with physical activity** | | | | | | |
| No trouble sleeping | Reference | — | Reference | — | Reference | — |
| **Physical activity pattern** | | | | | | |
| Inactive | 2.33 (1.67 to 2.98) | <0.001 | 2.29 (1.68 to 2.91) | <0.001 | 1.53 (0.94 to 2.12) | <0.001 |
| Insufficiently active | 1.05 (0.14 to 1.96) | 0.024 | 0.88 (0.04 to 1.72) | 0.041 | 0.48 (-0.31 to 1.28) | 0.230 |
| Weekend warrior | -0.14 (-1.36 to 1.09) | 0.823 | -0.50 (-1.71 to 0.71) | 0.414 | -0.31 (-1.54 to 0.92) | 0.619 |
| Regularly active | -0.19 (-0.74 to 0.36) | 0.502 | -0.37 (-0.91 to 0.18) | 0.183 | -0.56 (-1.05 to -0.07) | 0.027 |
| **Total energy expenditure (MET-min/week)** | | | | | | |
| **Insufficiently active** | | | | | | |
| 1 - 149 | 2.01 (0.13 to 3.89) | 0.036 | 1.99 (0.21 to 3.76) | 0.028 | 1.50 (-0.09 to 3.08) | 0.063 |
| 150 - 299 | 1.32 (-0.11 to 2.76) | 0.070 | 1.08 (-0.31 to 2.47) | 0.125 | 0.62 (-0.70 to 1.94) | 0.353 |
| 300 - 449 | 0.99 (-0.84 to 2.82) | 0.285 | 0.53 (-1.20 to 2.26) | 0.545 | 0.21 (-1.38 to 1.80) | 0.793 |
| 450 - 599 | 0.08 (-1.73 to 1.89) | 0.933 | -0.05 (-1.81 to 1.70) | 0.952 | -0.21 (-1.87 to 1.46) | 0.803 |
| **Weekend warrior** | | | | | | |
| 600 - 1199 | 0.07 (-1.95 to 2.08) | 0.948 | 0.21 (-1.74 to 2.16) | 0.830 | 0.64 (-1.39 to 2.66) | 0.534 |
| 1200 - 1799 | 0.28 (-2.53 to 3.09) | 0.844 | -0.10 (-2.99 to 2.80) | 0.947 | -0.37 (-3.09 to 2.35) | 0.786 |
| 1800 - 2399 | 2.87 (-1.49 to 7.24) | 0.195 | 2.68 (-1.54 to 6.89) | 0.210 | 2.13 (-1.40 to 5.66) | 0.233 |
| ≥ 2400 | -1.03 (-2.67 to 0.60) | 0.214 | -1.55 (-3.24 to 0.14) | 0.071 | -1.21 (-2.91 to 0.49) | 0.160 |
| **Regularly active** | | | | | | |
| 600 - 1199 | -0.74 (-1.74 to 0.26) | 0.146 | -0.90 (-1.90 to 0.10) | 0.079 | -1.01 (-1.92 to -0.10) | 0.030 |
| 1200 - 1799 | -0.73 (-1.74 to 0.28) | 0.152 | -0.73 (-1.72 to 0.26) | 0.147 | -0.86 (-1.79 to 0.06) | 0.067 |
| 1800 - 2399 | -0.30 (-1.66 to 1.06) | 0.663 | -0.50 (-1.83 to 0.83) | 0.455 | -0.67 (-1.73 to 0.38) | 0.208 |
| ≥ 2400 | 0.29 (-0.46 to 1.04) | 0.444 | 0.08 (-0.66 to 0.83) | 0.829 | -0.16 (-0.83 to 0.50) | 0.625 |
| **Frequency (session/week)** | | | | | | |
| **Weekend warrior** | | | | | | |
| 1 | 1.00 (-0.74 to 2.74) | 0.257 | 0.87 (-0.90 to 2.65) | 0.330 | 1.30 (-0.49 to 3.08) | 0.152 |
| 2 | -0.44 (-1.85 to 0.97) | 0.535 | -0.79 (-2.21 to 0.63) | 0.271 | -0.70 (-2.08 to 0.68) | 0.315 |
| **Regularly active** | | | | | | |
| 3 | 1.00 (0.42 to 1.59) | 0.001 | 0.71 (0.10 to 1.31) | 0.022 | 0.36 (-0.20 to 0.91) | 0.202 |
| 4 | -0.21 (-1.78 to 1.37) | 0.795 | -0.21 (-1.75 to 1.34) | 0.789 | -0.33 (-1.74 to 1.08) | 0.640 |
| 5 | -1.92 (-3.06 to -0.78) | 0.001 | -2.15 (-3.26 to -1.03) | <0.001 | -2.04 (-3.09 to -0.99) | <0.001 |
| ≥ 6 | -1.72 (-2.66 to -0.77) | <0.001 | -1.64 (-2.62 to -0.67) | 0.001 | -1.66 (-2.57 to -0.74) | 0.001 |
| **The proportion of VPA to total MVPA (%)** | | | | | | |
| **Insufficiently active** | | | | | | |
| ≤ 25% | 1.25 (0.33 to 2.17) | 0.008 | 1.02 (0.15 to 1.88) | 0.022 | 0.64 (-0.18 to 1.46) | 0.122 |
| 25.01 - 50% | -4.59 (-11.74 to 2.56) | 0.205 | -4.68 (-11.22 to 1.86) | 0.158 | -6.91 (-14.52 to 0.69) | 0.074 |
| 50.01 - 75% | 1.72 (-2.06 to 5.49) | 0.369 | 1.90 (-2.13 to 5.93) | 0.351 | 2.83 (-1.26 to 6.93) | 0.172 |
| ≥ 75.01% | -4.11 (-6.87 to -1.35) | 0.004 | -4.18 (-6.84 to -1.52) | 0.002 | -4.29 (-6.85 to -1.73) | 0.001 |
| **Weekend warrior** | | | | | | |
| ≤ 25% | 0.51 (-1.08 to 2.10) | 0.524 | 0.23 (-1.40 to 1.86) | 0.782 | 0.25 (-1.45 to 1.95) | 0.769 |
| 25.01 - 50% | -1.35 (-3.92 to 1.21) | 0.298 | -1.78 (-4.28 to 0.72) | 0.161 | -1.18 (-3.61 to 1.26) | 0.338 |
| 50.01 - 75% | -1.77 (-5.48 to 1.94) | 0.346 | -2.32 (-5.94 to 1.30) | 0.206 | -2.50 (-5.35 to 0.36) | 0.085 |
| ≥ 75.01% | -2.07 (-6.22 to 2.07) | 0.323 | -2.03 (-6.09 to 2.03) | 0.323 | -1.22 (-4.99 to 2.55) | 0.522 |
| **Regularly active** | | | | | | |
| ≤ 25% | -0.14 (-0.91 to 0.62) | 0.711 | -0.27 (-1.04 to 0.49) | 0.482 | -0.47 (-1.16 to 0.21) | 0.171 |
| 25.01 - 50% | -0.28 (-1.67 to 1.12) | 0.695 | -0.54 (-1.89 to 0.81) | 0.428 | -0.81 (-1.95 to 0.34) | 0.164 |
| 50.01 - 75% | -0.56 (-1.64 to 0.51) | 0.301 | -0.76 (-1.74 to 0.22) | 0.128 | -0.95 (-1.93 to 0.04) | 0.059 |
| ≥ 75.01% | 0.18 (-1.05 to 1.41) | 0.773 | 0.01 (-1.31 to 1.33) | 0.993 | -0.02 (-1.35 to 1.30) | 0.970 |
| **Physical activity pattern** | | | | | | |
| Sufficiently active | Reference | — | Reference | — | Reference | — |
| **Inactive** | | | | | | |
| No trouble sleeping | 1.30 (0.78 to 1.81) | <0.001 | 1.66 (1.14 to 2.18) | <0.001 | 1.42 (0.92 to 1.91) | <0.001 |
| Trouble sleeping | 2.78 (2.09 to 3.46) | <0.001 | 2.97 (2.33 to 3.61) | <0.001 | 2.18 (1.58 to 2.78) | <0.001 |
| **Insufficiently active** | | | | | | |
| No trouble sleeping | 0.49 (-0.02 to 1.01) | 0.058 | 0.69 (0.19 to 1.19) | 0.007 | 0.70 (0.20 to 1.20) | 0.007 |
| Trouble sleeping | 1.50 (0.61 to 2.38) | 0.001 | 1.50 (0.67 to 2.32) | 0.001 | 1.08 (0.30 to 1.86) | 0.007 |

**Fig. 3** The PA patterns and trouble sleeping combinations in relation to obesity in the older Americans. Sufficiently active: reporting at least 600 met-min/week in MVPA. Unadjusted Model: No adjustment for covariates. Model 1: Age, sex, education attainment, currently married/partnered, and race/ethnicity were adjusted. Model 2: Adjusted for smoking history, hypertension, diabetes, stroke, heart disease, and cancer in addition to Model 1

energy expenditure, compared to the inactive group, the insufficiently active group engaging in 150 to 599 MET-min/week, the weekend warrior group engaging in 1200 to 1799 MET-min/week ($\beta$ = -2.41; 95% CI = -4.03 to -0.78; $P = 0.004$) or 2400 MET-min/week and above ($\beta$ = -1.41; 95% CI = -2.48 to -0.35; $P = 0.010$), and the regularly active group engaging in 600 MET-min/week and above showed a significant negative association with BMI. Regarding PA frequency, compared to the inactive group, the weekend warrior group engaging in PA twice a week ($\beta$ = -1.56; 95% CI = -2.52 to -0.61; $P = 0.002$) and the regularly active group engaging in PA three times or more per week showed a significant negative association with BMI. In terms of the proportion of VPA to MVPA, compared to the inactive group, the insufficiently active group with VPA accounting for 75.01% and above of total MVPA ($\beta$ = -4.09; 95% CI = -5.52 to -2.65; $P < 0.001$), the weekend warrior group with VPA accounting for 0–50% of total MVPA, and the regularly active group with VPA accounting for 0–100% of total MVPA all exhibited significant negative associations with BMI. Regarding trouble sleeping, participants who reported trouble sleeping exhibited a significantly positive association with BMI compared to those without trouble sleeping ($\beta = 0.39$; 95% CI = 0.02 to 0.75; $P = 0.040$).

### Combinations of PA patterns and trouble sleeping in relation to BMI

Figure 3 presents the results of different combinations of PA patterns and trouble sleeping in relation to BMI. After adjusting for all covariates, compared to participants without trouble sleeping, the participants with trouble sleeping and inactive pattern showed a significantly positive association with BMI ($\beta = 1.53$; 95% CI = 0.94 to 2.12; $P < 0.001$). Conversely, participants with trouble sleeping and regularly active pattern exhibited a significant negative association with BMI ($\beta$ = -0.56; 95% CI = -1.05 to -0.07; $P=0.027$). Among participants with trouble sleeping, those who were insufficiently active or weekend warriors did not show a significant difference in BMI compared to those without trouble sleeping. Regarding total energy expenditure, participants with trouble sleeping and regularly active pattern engaging in 600 to 1199 MET-min/week ($\beta$ = -1.01; 95% CI = -1.92 to -0.10; $P=0.030$) exhibited a significant negative association with BMI. Regarding PA frequency, a significant negative association with BMI was found in participants with trouble sleeping who engaged in PA five or more times per week. In terms of the proportion of VPA to MVPA, participants with trouble sleeping and insufficiently active pattern, where VPA accounted for 75.01% and above of total MVPA ($\beta$ = -4.29; 95% CI = -6.85 to -1.73; $P<0.001$) exhibited a significant negative association with BMI. Furthermore, compared to participants meeting the WHO and CDC recommended PA levels, both the inactive and insufficiently active groups exhibited a significantly positive association with BMI, regardless of the presence of trouble sleeping.

## Discussion

This study demonstrates that both weekend warrior and regularly active patterns are negatively associated with obesity. Greater benefits are observed when older adults engage in regularly active pattern, with MPA and VPA each accounting for half of the total MVPA. Trouble sleeping is positively associated with BMI in older adults, but following a regularly active pattern may mitigate the impact of trouble sleeping on BMI. Additionally, regardless of whether trouble sleeping existed, older adults with insufficient PA face a positive association with obesity.

Our findings indicate that both weekend warrior and regularly active PA patterns are negatively associated with BMI. The effect may be explained by biological mechanism, such as PA stimulates the production of blood-borne signaling metabolites (Lac-Phe), which suppress appetite and mitigate obesity [54]. Additionally, our study suggests that regularly active pattern provides greater health benefits than weekend warrior PA pattern. A previous study highlighted a significant dose-response relationship between PA and BMI, with the most favorable outcomes consistently observed in participants who engage in regular PA, while weekend warriors showed moderate benefits [20]. This difference may be attributed to the lower frequency of PA in weekend warrior pattern, which leads to increased sedentary time during periods without exercise, independently affecting BMI [55]. Additionally, there is growing evidence suggesting that higher PA intensity may bring greater benefits [56]. However, we found that when VPA accounted for 25–50% of MVPA in the weekend warrior or regularly active patterns, the negative association with BMI was most significant. This combination of VPA and MPA may be particularly effective in initiating and maintaining PA in older adults [57], and further research is needed to explore its underlying mechanisms.

This study has identified a significant positive association between trouble sleeping and obesity in older adults. Disruptions in sleep can affect the hormone systems that regulate energy balance, such as cortisol, ghrelin, and leptin [15, 31, 58, 59]. Trouble sleeping increases cortisol production, potentially disrupting glucose homeostasis, inducing insulin resistance, and promoting visceral fat accumulation. These factors collectively elevate the risk of obesity [60]. Furthermore, trouble sleeping may inhibit leptin secretion and promote ghrelin production, leading to increased appetite [3]. These combined effects may drive older adults to consume more food, further increasing the risk of obesity [61].

Although trouble sleeping heightens the risk of obesity, regular PA can mitigate the effects on BMI. This effect is manifested in both PA indirectly improves obesity by enhancing sleep quality and directly influencing BMI [62]. PA promotes better sleep by elevating body temperature, boosting energy expenditure, and stimulating endorphin secretion, thereby fostering restorative sleep [63, 64] and reducing the impact of trouble sleeping on BMI increase. Furthermore, PA directly facilitate fat breakdown, increases energy expenditure, and address issues such as increased energy intake and reduced energy expenditure in older adults caused by trouble sleeping, thus improving obesity [65–68]. The dual effect of PA on trouble sleeping and BMI may explain why regular PA can ameliorate the impact of trouble sleeping on BMI increase. Our findings also highlight that insufficient PA is positively associated with BMI, regardless of the presence of trouble sleeping. This suggests that PA has a greater impact on obesity. Despite the ability of good sleep quality to maintain hormonal balance in the body [15], the lack of sufficient PA to stimulate fat oxidation can still heighten the risk of obesity in older adults. The coexistence of insufficient PA and trouble sleeping further exacerbates the risk of obesity. Moreover, when VPA constitutes 75% or more of MVPA in participants with trouble sleeping and insufficient PA, a significant negative association with BMI was observed. This suggests that VPA may play a crucial role in reducing BMI among individuals with trouble sleeping and insufficient PA. Future longitudinal studies and randomized controlled trials are needed to further explore this relationship.

This study represents the inaugural exploration of the interplay between PA patterns, trouble sleeping, and BMI in older Americans. However, several limitations should be acknowledged. First, since the participants were exclusively American, the results may not be generalizable to other countries. Second, the cross-sectional design of this study limits our ability to infer causality. Consequently, prospective investigations are imperative to delve deeper into causality. Third, the use of a single self-reported question to assess trouble sleeping may not capture the full complexity of sleep disorders. Finally, the use of self-reported methods to measure PA and trouble sleeping may present recall bias compared with objective measures.

## Conclusions

Insufficient PA and trouble sleeping in older adults are positively associated with obesity. Implementing either a weekend warrior or regularly PA lifestyle is negatively associated with obesity. Greater benefits can be achieved when a regular PA routine is followed, with MPA and VPA each accounting for half of the total MVPA. Furthermore, adopting a regularly active lifestyle can improve the negative correlation between trouble sleeping and obesity. However, regardless of the presence of trouble sleeping, insufficient PA remains positively associated with obesity in older adults.

### Abbreviations

| | |
|---|---|
| 95%CI | 95% Confidence Interval |
| ANOVA | Analysis of Variance |
| BMI | Body mass index |
| NHANES | National Health and Nutritional Examination Survey |
| PA | Physical activity |
| MPA | Moderate-intensity physical activity |
| VPA | Vigorous-intensity physical activity |
| MVPA | Moderate-to-vigorous intensity physical activity |
| WHO | World Health Organization |
| CDC | Centers for Disease Control and Prevention |
| GPAQ | Global Physical Activity Questionnaire |
| MET | Metabolic equivalent task |
| MEC | Mobile Examination Center |
| SD | Standard deviations |

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### Author contributions

Xiao Hou: methodology, resources, writing-review and editing, visualization. Huihui Wang: formal analysis, resources, writing—original draft preparation. Zhengxing Yang: methodology, writing—review and editing. Yuanyuan Jia: investigation, validation, writing—review and editing. Yifan Lv: validation, data curation, writing—review and editing. Xiaosheng Dong: conceptualization, formal analysis, writing—review and editing, supervision.

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### Data availability

The datasets used and analyzed during the current study available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

This study utilized publicly available data from NHANES cycles 2007–2008 to 2017–2018. All NHANES protocols were reviewed and approved by the National Center for Health Statistics Research Ethics Review Board (Protocol #2005–06), and written informed consent was obtained from all participants during data collection.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

### Author details

[1]Key Laboratory of Sports and Physical Health, Ministry of Education, Beijing Sport University, Beijing, China
[2]School of Sport Science, Beijing Sport University, Beijing, China
[3]School of Physical Education, Fuyang Normal University, Fuyang, China
[4]People's Public Security University of China, Beijing, China
[5]Department of Social Medicine and Health Management, School of Public Health, Cheeloo College of Medicine, Shandong University, Jinan, China
[6]Key Lab of Health Economics and Policy Research, National Health Commission of China, Shandong University, Jinan, China
[7]Centre for Health Management and Policy Research, School of Public Health, Cheeloo College of Medicine, Shandong University, Jinan, China
[8]Institute of Health and Elderly Care, Shandong University, Jinan, China

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